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Laboratory investigation on use of fly ash plastic waste composite in bituminous concrete mixtures

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Abstract

This paper reports the benefits of composite of fly ash and plastic waste in Bituminous Concrete (BC) mixture for construction of flexible pavement. Fly Ash (FA) and Plastic Waste (PW) are two abundantly available waste materials, with several good characteristics, making them suitable for bituminous road construction. The plastic waste will improve some properties of the bituminous mix and also solve environmental problems. Fly ash is the finely divided residue that results from the combustion of pulverized coal. It can be used as cost-effective mineral filler in hot mix asphalt (HMA) paving applications. The Thermal degradation behavior of the plastic waste was investigated by Thermo Gravimetric Analysis (TGA). Samples were prepared using various percentages of plastic content from 0.25% to 1% with 0.25% increment by weight of the total mix. From the tests it was found that the optimum content of plastic is 0.75% and the optimum binder content of bitumen for fly ash as filler is 5.3% and fly ash-plastic waste composite is 5.4%. Samples were prepared using 0.75% plastic content and optimum binder content of bitumen by weight of total mix. The designed BC mixes such as mixture containing fly ash as well as fly ash- plastic waste composite were prepared in a laboratory mixer and are designated as BC A and BC B respectively. The BC mixtures were subjected to performance tests such as indirect tensile strength, indirect tensile strength ratio, static creep and resilient modulus at different temperatures and rutting resistance by wheel tracking test. From the indirect tensile strength ratio (TSR) it is found that, the TSR of BC B was 10.3% higher than the BC A mix indicating better resistance to moisture damage. From the static creep test it is found that the permanent deformation of BC B is higher than the BC A at both the temperatures 35°C and 45°C but percentage of recovery is higher for BC B than the BC A mix. Resilient modulus values of BC B was higher than the BC A at both the temperatures 35°C and 45°C.Higher values of resilient modulus values indicate that they are very high and support to reduce rutting behavior of mixtures. Rut depth of BC B is 15.9% lower than the BC A. These findings indicate that BC containing composite as substitute of traditional filler is an acceptable material for bituminous road construction.

Keywords: Bituminous concrete; Fly ash; Plastic waste; composite; Modulus

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1. Introduction

It is well known that sources of good quality mineral aggregate including traditional fillers (lime, cement, etc) are depleting fast due to large scale development of road infrastructure in India. Therefore, there is a quest to explore use of waste mineral materials like fly ash as filler. Presently, about 100 thermal power plants operating in India are producing over 170 million tons of ash every year, which is dumped in the land adjoining to thermal power plants, adversely affecting nearby environment besides consuming useful land. It is estimated that production of ash is likely reach to 600 million tons in 2030 (Chandra et al, 2011). Highway sector has potential to utilize sufficient quantity of waste materials, if their effect on performance of pavement proves to be technically, economically and environmentally acceptable and meet the requirements of standards and specifications (Chandra et al, 2011). Fly Ash (FA) and Plastic Waste (PW) are two abundantly available waste materials, with several good characteristics, making them suitable for bituminous road construction (Kumar et al, 2008, Jain et al, 2011).Fly ash is finely divided residue resulting from the combustion of coal. The quantity of fly ash is growing along with the steady global increase in coal use. Coal fly ash has been successfully used as a mineral admixture in Portland cement, as a constituent material of mortars, concretes and flowable fill mixtures, as cost-effective mineral filler in hot mix asphalt paving applications, etc. One of the major benefits of using fly ash is that it will considerably reduce the use of natural raw materials and thus will enhance industrial sustainability. However, the ash that isn't used ends up in landfills or containment ponds. In order to increase its utilization, an investigation was carried out to evaluate its potential to use as mineral filler in bituminous mix.

Disposal of waste has become a great problem in cities .Disposal of waste plastic bags is one such menace. The main problem with plastic is, it will be thrown on roads and dumped in dustbins and drains. The waste plastic bags, which are dumped, find their way into drainage systems and aesthetic problems. One of the promising option currently under investigation is the use of such waste plastic to modify the bituminous mixes used for paving roads .The plastic waste need to be process separately. This plastic will improve some properties of the bituminous mix and also solve environmental problems. Solid plastic litter generated from used plastic goods and grocery bags is non bio-degradable (Jain et al, 2011) and its disposal is a serious concern.

A field performance study on use of fly ash in bituminous road surfacing was conducted by Swaminathan et al, (1968). The findings of study found satisfactory performance for medium traffic. A study on characterization of Indian fly ash for use in bituminous road construction has been conducted recently (Sharma et al, 2011). A critical review on use of fly ash in bituminous road construction is also reported indicating possibility of its use in bituminous mixes (Kandhal, 1993). Kumar et al, (2008) conducted laboratory studies on use of fly ash in bituminous mixes. Studies on viscosity of fly ash and bitumen mixture have been conducted by Kavussi and Hicks, (1997). It is also reported that an increase in fly ash content up to 6 %, yields significant improvement in fatigue life of mixes. Tapkin et al. (2008) evaluated the effect of fly ash as a filler replacement on the mechanical properties of asphalt mixture and found that fly ash can be used effectively in a dense-graded wearing course as a filler replacement. The effect of waste polymer modifier (WPM) on properties of bituminous concrete mixes has been recently investigated by Sangita et al, (2011). In a recently study by Vasudevan et al, (2006), plastic coated aggregate bitumen mix was found to perform better. Results of a study done on use of waste polymeric packaging materials in modification of bituminous mixes have been reported recently by Jain et al (2012). The study found that plastic waste improves properties of bituminous mixes. Verma S.S. (2008), Concluded that Plastics will increase the melting point of the bitumen. This technology not only strengthened the road construction but also increased the road life.

In view of above cited literature and associated problems with disposal of fly ash as well as plastic waste, a study on use of these solid waste materials in roads construction was initiated. In this investigation a composite is prepared by blending fly ash and waste plastic. Mixture characteristics are heavily dependent on the properties of the aggregate and bitumen that constitute the paving mixture. The filler is an integral part of the aggregate used in bituminous mixtures, so its characteristics and content in the mix are very important for modifying the mixture characteristics. The optimum bitumen content and air voids percentage, and thus all mechanical properties of mixture, are influenced by the filler. The main aim of this study is to evaluate mechanistic properties of bituminous concrete mixtures using the composite of fly ash and plastic waste.

2. Materials

Plastic waste (PW) in the shredded form (2-8 mm) was used in this study. Properties of shredded plastic waste are given in Table 1. Fly ash used in this study was obtained from NTPC Ltd. Dadri, (U.P) India. The bulk density, specific gravity and water absorption tests were performed using standard methods and the test results are presented in Table 2. The VG-30 grade paving bitumen from Mathura refinery of India was used. The physical properties of bitumen are described in Table 3. The mineral aggregate (granite) was obtained from a local quarry and its physical properties are given in Table 4.

Table 1.Properties of plastic waste

Properties	Test Method	Value
Initial Decomposition Temperature, °C	TGA Curve	399 °C
Melting Temperature, °C	DSC Curve	124-129 °C

Table 2. Properties of fly ash used

Properties	Test Method	Values
Bulk Density, gm/cm^3	IS: 2386 (Part III)	1.21
Specific Gravity	IS: 2386 (Part III)	2.1
Water absorption, %	IS: 2386 (Part III)	1.59
Fineness modulus	IS: 2720 (Part IV)	2.44
Methylene Blue	IS: 2720	0.59
Plasticity Index	IS: 2720	Non Plastic

Table 3. Properties of bitumen (VG-30) used in the present study

Properties	Test Method	Value	Specification IS 73: 2006
Penetration, (25°C, 100 g, 5s), 0.1 mm	IS 1203-1978	61	50 – 70
Softening point (Ring and Ball), °C	IS 1205-1978	47	46- 54
Ductility at 27°C (5 cm/min)	IS 1208-1978	75+	>75
Specific gravity	IS 1202-1978	1.01	>0.99
Viscosity at 60°C, Poise	IS 1206-1978	2449	>2400
Viscosity at 135°C, cSt	IS 1206-1978	360	>350

Table 4. Properties of mineral aggregates (granite)

Properties	Test Method	Value	MoRTH ,2001 Specifications
Aggregate Impact Value, %	IS 2386 (Part IV)	10.10	30 max
Water Absorption Value, %	IS 2386 (Part III)	1.137-1.592	2 max
Specific Gravity	IS 2386 (Part II)	2.651-2.701	2.5-3.0
Combined (EI + FI) Index, %	IS 2386 (Part I)	26	30 max
Stripping, %	IS 6241	99	Min retained coating 95

El: Elongation Index FI: Flakiness Index

3. Design of Bituminous concrete mixtures and Preparation of mixtures

Grading of aggregate was done as per Ministry of Road Transport and Highways Specification (MoRTH, 2001) for 50 mm thick bituminous concrete is given in Table 5 and its gradation was shown in Figure 1. For the preparation of bituminous mixtures aggregate was heated to 160 ºC in a pan and requisite quantity of bitumen was then added to heated aggregate. In case of preparation with plastic waste the dosage of plastic waste was added to heated fly ash and mixed for 10 minutes then added to heated aggregate at 160 ºC and mixed for few minutes. The samples were prepared using various percentages of plastic waste from 0.25% to 1% wit 0.25% increment by weight of total mix. From the test results the optimum quantity of plastic waste was found to be 0.75 % by weight of total bituminous mix and these test results were shown in Table 6. The designed BC mixes such as mixture containing fly ash as well as fly ash- plastic waste composite were prepared in a laboratory mixer and are designated as BC A and BC B respectively. Samples were prepared using the Marshall method (ASTM D 1559) by application of 75 blows on both faces. The properties of the designed BC mixtures (BC A and BC B) are given in Table 7.

Table 5: Gradation of Bituminous Concrete Mixes

Sieve Size mm	Cumulative % passing	Specified Grading
19.0	100	79-100
13.2	69	59-79
9.5	62	52-72
4.75	45	35-55
2.36	36	28-44
1.18	27	20-34
0.60	21	15-27
0.30	15	10-20
0.15	9	5-13
0.075	5	2-8

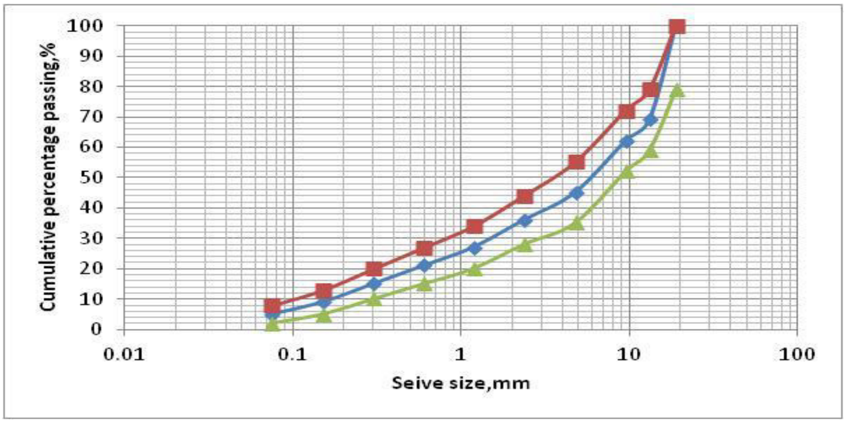

Figure 1 Gradation of the Bituminous Concrete.

Table 6: Properties of Designed BC Mixtures with various percentages of plastic waste

Properties	Method	Waste plastic % 0	0.25	0.5	0.75	1
Bulk Density, g/cc	ASTMD2726	2.36	2.37	2.4	2.37	2.33
Air Voids, %	ASTMD3203	5.26	5	4.3	4.47	5.3
Marshall Stability Kg, 60ºC	ASTMD 1559	1176	1036.5	1280.5	1480	1332
Marshall Flow, mm at 60ºC	ASTMD 1559	3.4	3.2	3.6	4.35	3.85
Marshall Quotient,kg/mm	Stab/Flow	346	324	356	340	346

Table 7: Properties of Designed BC Mixture

Properties	Method	BC A	BC B
Bulk Density, g/cm^3	ASTMD2726	2.343	2.351
Air Voids, %	ASTMD3203	5.26	4.47
Bitumen Content, %	ASTMD 3203	5.3	5.4
Marshall Stability Kg, 60ºC	ASTMD 1559	1176	1480
Voids in Mineral Aggregate (VMA)	ASTMD 1559	17.5	17
Voids filled with Bitumen (VFB)	ASTMD 1559	70	73.8
Marshall Flow, mm at 60ºC	ASTMD 1559	3.1	3.4
Marshall Quotient,kg/mm	Stability/Flow	379	435
Un conditioned Indirect Tensile Strength, Kg/cm^2	ASTM D 4867	8.68	11.88
conditioned Indirect Tensile Strength, Kg/cm^2	ASTM D 4867	7.01	10.21
Tensile Strength Ratio,%	ASTM D 4867	81	86
Stiffness Modulus MPa, 35ºC	ASTM D 4123	2868	4407
Retained stability,%	IRC SP: 53-2002	76	82

4. Laboratory Investigations

Details of test procedures are given in following sections

4.1. Indirect tensile strength (ITS) test

Indirect tensile strength test is useful to evaluate resistance of compacted bituminous mixture to cracking as well as sensitivity of mixture to moisture damage. To identify whether the coating of bitumen binder and aggregate is susceptible to moisture damage, Tensile Strength Ratio (TSR) is determined according to ASTM D 4867. TSR is the ratio of average indirect tensile strength of conditioned specimens to the indirect tensile strength of unconditioned specimens. The sample was prepared as per standard by maintaining 7% air voids. The conditioned specimens (set of three specimens) were placed in a water bath maintained at 60°C for 24 hours and then placed in a water chamber maintained at 25°C for 1 hour. The unconditioned samples were placed in water bath maintained at 25°C for 20 minutes. These specimens were tested for their tensile strength. The failure load was recorded and the indirect tensile strength (St) was calculated using following Equation (1)

$$s_t = \frac{2P}{\pi t d} \tag{1}$$

Where, P is the load (kg), d is the diameter in cm of the specimen; t is the thickness of the specimen in cm. The Tensile Strength Ratio (TSR) of specimen was computed by considering Equation (2).

$$TSR = \left(\frac{S_{tc}}{S_{tuc}}\right) * 100 \tag{2}$$

Where TSR is tensile strength ratio S_{tc} average indirect tensile strength of conditioned specimens and S_{tuc} is indirect tensile strength of unconditioned specimen Results of tensile strength and TSR are plotted in Figure 2.

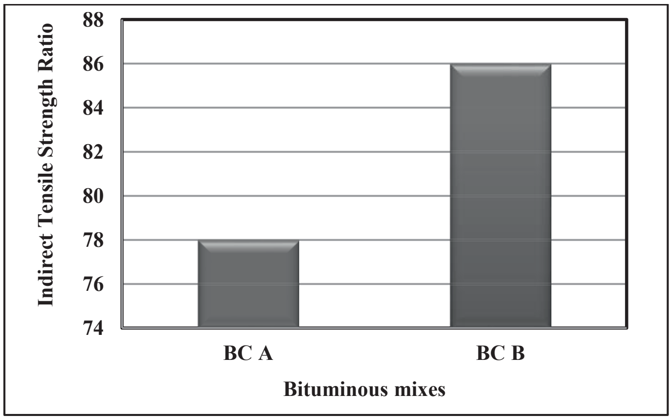

Figure 2 Tensile strength Ratio of Bituminous Mixes

4.2. Resistance to deformation

The aspect of deformation at high temperature has been investigated by conducting rutting and static creep tests.

4.2.1 *Rut depth studies by wheel tracking test*

Rutting is an important parameter for design as well as for evaluation of performance of a BC mixture. To check the rutting resistance of the BC mixtures, tests were performed using a Wheel Tracking Device (WTD), which is a destructive test and involves direct contact between the loaded wheel and the rectangular test specimens. The test was conducted on prepared slab specimens of 300*300*50 mm at optimum binder content containing fly ash and fly ash plastic waste composite as filler. The test was conducted as per BS: 598-1998. The test applied 20,000 passes at 45 °C and resulting rut depth was measured. The rut depths of different BC mixtures are plotted in Figure 3. Also the rut depth in different cycle range is presented in Table 8.

Table 8: *Rutting in BC mixtures*

Composition of composite	Rutting in mm at 45 °C for different cycle range		
	0 - 5000	5000 - 10000	10000 - 20000
BC A	2.2	3.2	3.91
BC B	2.7	3.05	3.29

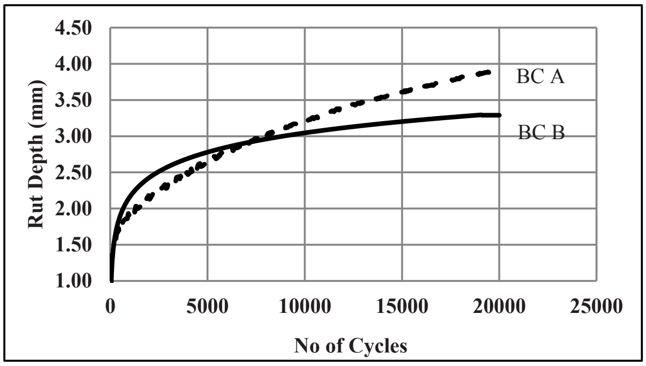

Figure 3 Rut depth Versus No of cycles of BC mixtures

4.2.2 *Static creep test*

A static creep test is conducted by applying a static load to a specimen and then measuring the permanent deformation of the specimen after unloading. The test is used to determine the permanent deformation of the asphalt mixtures. The observed permanent deformation of the asphalt mixtures was then correlated with the rutting potential. The creep deformation of a cylindrical specimen under a Uni-axial static load was measured as a function of time, and the sample dimensions and test conditions were standardized. After initial elastic response, the creep portion of the response curve eventually becomes linear, giving constant slope. After the release of the applied stress the elastic deformation recovers followed by the time dependent recoverable elastic deformations, the residual strain which exists after complete elastic recovery is the non recoverable permanent deformation. Permanent deformation risk was greater under heavy loads and high temperature. So the following test parameters were selected: the uniaxial load was 100 KPa (0.1 MPa), the temperatures were 35°C and 45°C, and the load duration was 3600 s and unloading duration was 2000s. The values of permanent deformation, percentage recovery and creep modulus of creep test are presented in Table 9. The creep deformation obtained during test at 35°C is presented in Fig 3.

Table 9: Test result of Static Creep

Temperature (^{0}C)	BC Mix	Total Deformation (mm)	Permanent Deformation (mm)	Recovery (%)	Modulus (Mpa)
	BC A	0.26	0.14	54	13.62
35	BC B	0.27	0.19	70	14.31
	BC A	0.21	0.09	41	15.8
45	BC B	0.22	0.12	54	15.83

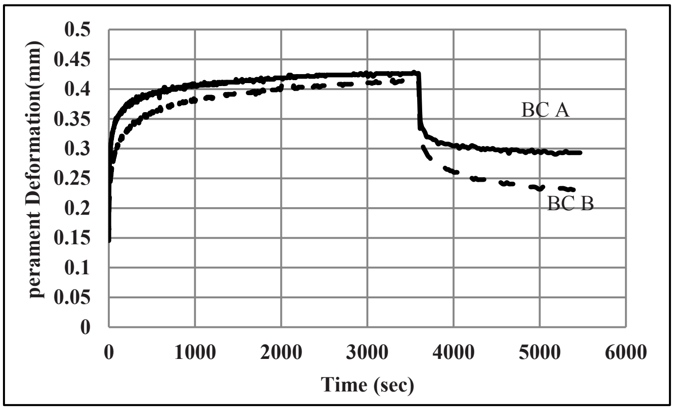

Figure 4 Static creep test of Different mixtures at 35°C

4.3. Resilient modulus (M_R) test

Resilient Modulus (M_R) is one of the most important mechanistic properties of bituminous mixture. To check the effect of composite on the resilient modulus values at different temperatures, the repeated loading indirect tensile test on compacted bituminous mixtures was performed as per ASTM D-4123. The test was conducted by applying the compressive load in the form of haversine wave at 25°, 35°, and 45°C for two BC mixtures. The specimens were conditioned for 5 hr in the environmental chamber at the given temperature and then subjected to repeated loading pulse width of 100 ms, and pulse repetition period of 1000 ms. The results are plotted in Figure 5.

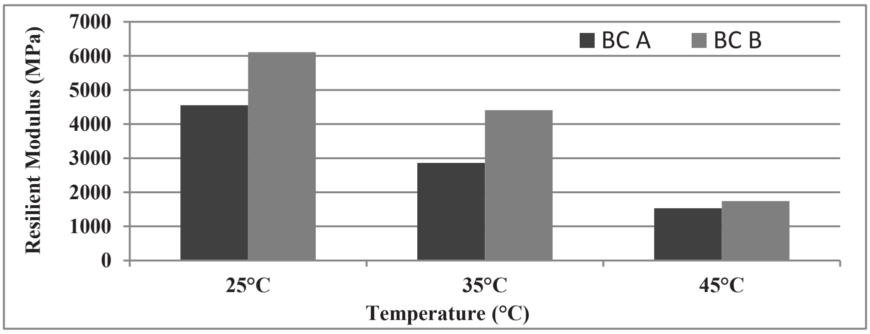

Figure 5 Resilient Modulus at Different mixtures at various temperatures

5. Discussion of test results

Properties of plastic waste are given in Table 1. The particle size of shredded plastic is in the range of 2-8 mm, which lies in conformity of findings reported earlier by Jain et al (2011). The melting temperature of PW was 124-129^{0}C which melts at the heating temperature of aggregate and fly ash and the decomposition temperature is 399^{0}C, where PW changes its chemical properties. Therefore, PW can be used until 125-200^{0}C temperature. Results of test performed on fly ash as described in Table 2 indicate that the ash used in this study was non plastic. A low value of methylene blue indicates, low amounts of clay and organic material in the fly ash. Data given in Table 7 reveals that the optimum bitumen content was in the range of 5.3% for fly ash and 5.4% for fly ash and plastic waste composite by weight of aggregate. TSR is widely accepted test to address damage caused by the ingress of moisture. The values of TSR of BC A and BC B are recorded as 78%and 86%. BC with plastic waste composite filler has tensile strength ratio 10.3% higher indicating better resistance to moisture damage. Therefore, BC mixes containing plastic waste composite as filler may be used in locations of high rainfall.

Wheel tracking and static creep tests are done to study the performance with respect to permanent deformation of the two BC mixtures at higher temperatures.

Rutting test

Rutting is key factor for design as well as evaluation of the performance of BC mixtures. It can be seen from Figure 3 the observed rut depth values of BC mixtures are in the range of 3.29 to 3.91 mm using VG 30 bitumen binder and fly ash and fly ash / plastic waste composite as filler. Data plotted in Figure 3 indicate that higher resistance to rutting is observed when composite is used. The rate of rutting is lower for BC mixture containing composite as filler as shown in Table 8.

Static creep test

Results plotted in Figure 4 indicated that values of creep modulus are higher for BC containing composite. The value of permanent deformation was more in BC containing composite but the percentage of recovery is high for BC containing composite.

Resilient modulus Test, M_R (ASTM D 4123)

Resilient modulus is the most important variable for mechanistic design of flexible pavement structure. It is the measure of pavement response in forms of dynamic stress and corresponding strains. The data plotted in Figure 5 indicate that use of composite as filler has improved the diametric resilient modulus of the mixes as compared to BC mixture with fly ash at all the test temperatures. For the mixture, containing plastic waste composite in BC the value of 1742.5 MPa is observed at 45°C as compared to 1529.5 MPa. The average resilient modulus values at 35 °C increased from 2862 MPa to 4407 MPa upon addition of composite. Values of M_R at 45°C are very high and support to reduce rutting behavior of mixtures, when tested by wheel tracking test at same temperature. The pozzolanic properties of fly ash together with elastic properties of plastic waste contributed to high values of M_R at 35 °C and 45 °C, resulting to overall improved performance.

6. Conclusions

Following are the conclusions are drawn from the present study.

- Fly ash can be used as filler in bituminous concrete mixture. Properties of Bituminous concrete can be further improved by coating of fly ash with plastic waste
- The TSR value for BC B is 10.3% higher than BC A which clearly indicate the improvement in the moisture sensitivity of mix.

- M_R value at 35 °C and 45 °C for BC B is 53.9 and 13.92% higher than the BC A. This may attribute due to decrease in air voids thus providing stiffer mix. Therefore, use of the composite led to an increase in indirect tensile strength. Incorporation of the composite increased values of M_R at 35 °C and 45 °C
- Plastic waste composite reduced rutting in bituminous concrete mixture during wheel track testing.
- Composite improved creep modulus and creep recovery in Bituminous concrete mixture
- Some further investigations are deemed necessary to validate the results.

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